Uniform Circular Motion

"The difficulty lies not in new ideas, but in escaping from old ones."

J. M. Keynes

OBJECTIVE:

To study the relation between force and acceleration in circular motion.

THEORY

An object traveling in a circle of radius *r* with constant speed *v* has an acceleration

$$a = \frac{v^2}{r} = r\omega^2 \qquad (1)$$

directed toward the center of the circle. Here, ω is the angular speed of the object. Newton's second law states that $\vec{F} = m\vec{a}$. An external force, of magnitude

$$F = \frac{mv^2}{r} = mr\omega^2 \qquad (2)$$

must therefore be present to cause this acceleration. The present experiment should convince you that this expression and the logic leading to it are correct.

EXPERIMENTAL PROCEDURE

The apparatus is sketched in Fig. 1. A plumb-bob, *B*, hangs from a cross-arm, which you can rotate by hand. The force to keep the plumb-bob moving in a circle once the plumb-bob has been set to rotate is provided by a spring. The force provided by the spring, F, is calibrated by hanging metal pieces, *M*, from the apparatus as shown in Fig. 1. **DO NOT attach the hanging metal pieces onto the apparatus when you are rotating the plumb-bob. The radius *r* is the distance between the adjustable index rod and the center of the spindle. For this experiment, you have to move the index rod to change *r* , and you have to measure *r* with a ruler. The angular speed of the plumb-bob, ω, is determined with a photogate.**

To begin the experiment, measure the mass of *B* with a scale. **You can find a scale at both the front of the lab room.** You should then hang the plumb-bob from the string attached to the crossbar. **DO NOT** connect the plumb-bob to the spring **or** the hanging metal pieces, M, at this point. **Set the index rod for the largest *r* the apparatus will allow**, and adjust the cross-arm so that *B* hangs directly over the index rod **when neither the spring nor the hanging metal pieces are connected to *B*.** Next you should adjust the leveling screws which are the three metal screws located on the base of the apparatus until the spindle does not tend to rotate when released. When you have done this, check to see that the counterweight roughly balances the cross-arm, and that *B* is still centered over the index rod. Why do you need to level the apparatus? The photogate is placed so that the metal flag on the spindle will interrupt the beam once during each full turn of the spindle.

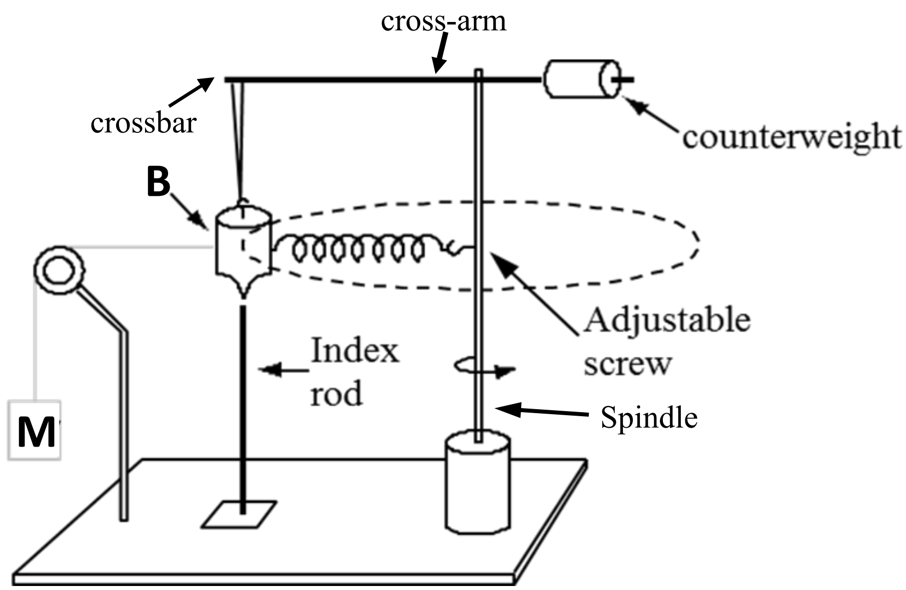


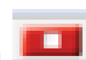
Figure 1 Centripetal force apparatus. When the spindle is turned the plumb-bob B follows the dashed circle. The hanging metal pieces, M, and string, shown in gray, are used to measure the spring force ***when the apparatus is not rotating****.*

Once the apparatus is properly set up, you can measure ω and F for motion in a circle of known radius. **Note, ω and F are measured separately.**

To measure ω, connect the spring between *B* and the spindle, **but with the hanging metal pieces, M, disconnected from *B*.** Note, once you have attached the spring to *B*, the plumb-bob **SHOULD NOT** be hanging over the index rod. The adjustable screw at the spindle end of the spring allows you to set the stretched length of the spring, and hence the force exerted by the spring on the plumb-bob when the plumb-bob is rotating. Using your fingers, smoothly and gradually rotate the spindle with increasing speed until the plumb-bob is moving in a constant-diameter circle which passes directly over the index rod. **<u>In order to get the plumb-bob to pass over the index rod after the spring is attached, you may have to rotate the plumb-bob quite fast.</u>** Once B is moving directly above the index rod, you should stop rotating the spindle. *Keep your hands and head out of the path of the moving plumb-bob to avoid damage.* Explain why the radius of rotation increases as you spin the plumb-bob, and once you stopped rotating the plumb-bob, the plumb-bob moves in a circle of approximate constant diameter.

Once you are comfortable with the procedure to get the plumb-bob rotating at a set diameter, **<u>Plug the power adapter for the "Vernier Lab pro" box into a power outlet if you have not already done so,</u>** start LoggerPro from the file **Circle.cmbl** **<u>on the computer's desktop</u>**. Rotate the spindle with increasing speed until the plumb-bob is moving in a constant-diameter circle which passes directly over the index rod. Once the plumb-bob is moving directly over the index rod, stop rotating the spindle and click  to start the measurement of ω. The software will measure the time Δt for each rotation of the spindle, and calculate ω from

$$\omega = \frac{2\pi}{\Delta t} \qquad (3)$$

Collect data until you have **<u>several consistent values of ω on the graph</u>**, then click on  and slowly halt the rotation. Click and drag the mouse on the graph to select the data over a period of steady rotation (relatively constant ω). Then use Analyze > Statistics or click  in the tool bar to obtain the mean of the selected data. Record the mean angular speed as your estimate of the angular speed.

Right after you measured the ω for a particular value of r and stretched length of the spring you need to measure **F**, the force that was used to keep the plumb-bob moving at a circle of radius r with a constant speed.

<u>To measure *F*</u>, attach a string and hanging metal pieces, *M,* to the plumb-bob, *B*, while the plumb-bob is at rest, as shown in Fig. 1. Select the hanging metal pieces *M* so that *B* is again centered over the index rod. (You may not be able to get B to center exactly over the index rod with the metal pieces available on your table. You may consider setting the distance between your index rod and the spindle based on the metal pieces you have available on your table.) **<u>The spring must now be exerting as much force on *M* as it did on *B* while *B* was rotating above the index rod, so you now know the force that was acting on *B* when you measured ω.</u>**

Take data so that you can make a plot of **the measured *F*** versus **the measured $r\omega^2$ (F must be the values that is plotted along the vertical axis)** for six unique values of $r\omega^2$. Three of the unique values of $r\omega^2$ could be achieved by changing the distance between the index rod and the spindle while maintaining the same distance between the plumb-bob and the spindle when the plumb-bob is connected to the spindle via the spring. **After changing the distance between the index rod and the spindle, you must adjust the cross-arm so that *the plumb-bob* is positioned over the index rod when neither the spring nor the hanging metal pieces are connected to *the plumb-bob*.** To achieve another three unique values of $r\omega^2$ you could maintain the same distance between the index rod and the spindle and change the distance between the plumb-bob and the spindle when the plumb-bob is connected to the spindle via the spring by tightening or loosening the adjustable screw on the spindle (see figure 1).

To plot your data you can use the file **Graph.cmbl** **on the computer's desktop.** Overall you should have at least 6 different data points on your plot.

Which part of the procedure do you think is the least accurate, determination of ω, r, or F? Explain your answer. Discuss the shape of the plot you obtain. Is F directly proportional to $r\omega^2$? Attach your plot of F vs $r\omega^2$, including a **proportional fit** **(y=Ax)**. You can find the option to fit your data with a proportional fit under Analyze > Curve Fit. Does the data follow a proportional relationship? What is the slope of the fit line? What is the expected value for the slope of the fit line? Is the slope of your fit line equal to the expected value with the uncertainty? **Please unplug the power adapter of the "Vernier Lab pro" box from the power outlet once you finished collecting data.**